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LARGE SCHOOL BUS DESIGN VEHICLE DIMENSIONS

MBTC FR 1054-1

J. L GATTIS and
MICHEAL D. HOWARD

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16. Abstract

A survey of United States school bus operators and manufacturers was conducted to defined the larger sizes of school buses in regular use. A mid-60 passenger type-C bus (SB-C) and a mid-80 passenger type-D bus (SB-D) were selected as design vehicles. Both the dimensions (length, width, etc.) and the trace of turning path swept through 90° and 180° right turns were measured. During field tests, these school buses made turns somewhat sharper than those of the AASHTO design single unit or bus vehicles. Simulation methods such as computer-generated templates replicate the field turns fairly well in mid-turn, but do not well replicate the spiral at the end of a turn. The long rear overhang of these school bus design vehicles allows the outer rear corner of the vehicle to swing outside the wheel path at the beginning of a turn, and therefore be a design consideration in some situations. Recommended SB-C and SB-D turning path templates were developed and presented.

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by J. L. Gattis, Ph.D., P.E., and Micheal D. Howard

CHAPTER 1
INTRODUCTION

The physical and operating characteristics of vehicles that will be using a roadway are important controls affecting the geometric design of a new roadway. Characteristics of interest to roadway design engineers include a vehicle's dimensions, weight, turning radii, offtracking, acceleration, and braking. To properly design roadways or other facilities, the largest vehicle expected to use the facility with considerable frequency will be used as a design vehicle (*AASHTO, 1994*), and the physical and operating characteristics of this vehicle will be used to design the facility.

No school buses are included among the fifteen design vehicles presented in both the 1990 *Green Book (AASHTO, 1990)* and the 1994 *Green Book (AASHTO, 1994)*. These American Association of State Highway and Transportation Officials (AASHTO) publications do contain two design vehicles, the single unit truck (SU) and the single unit [urban transit] bus (BUS), that roadway design agencies have used as surrogates for school buses. The *Green Book* states "the 'SU' design vehicle characteristics are suitable for all single-unit trucks and small buses; the control dimensions for its minimum turning path suffice for a number of buses and truck combinations now in operation. On most facilities serving truck traffic or large buses, however, the design vehicle either for semitrailer combinations or large buses should be considered in design...A design vehicle designated BUS with a 25-ft wheelbase and an overall length of 40 ft...has been selected."

The purpose of this research project was to generate and present roadway geometric design characteristics (dimensions and turning characteristics) for large or full-size school buses. The objectives of this study were:

1. to identify what full-size school buses are being used by larger school districts in the nation,
2. to select design vehicle candidates,
3. to identify dimensions of candidate design vehicles,
4. to estimate turning path and turning radii using various simulation models,
5. to identify the turning radii at crawl speeds by taking field measurements, and
6. to investigate the effects of a large overhang behind the rear axle of many large school buses.

The bus turning paths/radii of interest were those of the outer front wheel (also known as the design radius), the outer front body (also known as the maximum radius), and the inner rear wheel (also known as the minimum radius).

None of the *Green Book* turning templates for AASHTO design vehicles show the rear overhang path. However, a large rear overhang could cause the outside rear trace of the bus body to be a controlling design factor.

The final task was to combine the gathered information and field test results to develop school bus design-vehicle dimensions and turning paths.

CHAPTER 2
BACKGROUND

Vehicle characteristics which affect roadway design include the minimum turning radius, the wheelbase, and the path of the inner rear tire *(AASHTO, 1994)*. The turning path boundaries are determined by the outer trace of the outer front overhang and the path of the inner rear wheel.

Geometric design requirements are more severe for trucks and buses than for passenger cars due to longer wheelbases and greater turning radii. The longer single unit trucks and buses require greater turning radii due to their greater offtracking. Offtracking is the phenomenon by which the vehicle's rear wheels do not follow the same path as the front wheels; this is very obvious during slow speed, sharp turns.

A literature search was performed in an attempt to find any testing of school buses, the results of such testing, or any methodology for testing that could be utilized. Little literature was found on the testing of the geometric design attributes of school buses. Testing tractor-trailer combinations has been a popular research topic in the past decade, and articles written about these tests provided ample literature about testing methods.

BUS DESIGN LITERATURE

School bus standards are presented in the *1995 National Standards for School Transportation (CMSU)*, which states that the overall length of school buses shall not exceed 40' [12.1 m] and the overall width shall not exceed 102" [8.5', 2.6 m].

Larger or "full-size" school buses are manufactured in one of two configurations *(CMSU)*. The first configuration is the "conventional" type (type C) school bus. A type C school bus has an engine located in front of the windshield and under a projecting nose. The entrance door is located behind the front wheels. The second configuration is the flat-nosed "transit-style" (type D) school bus. The engine of a type D school bus may be located at either the front (behind the windshield) or the rear. The entrance door is located ahead of the front wheels. Both types are designed to carry more than ten persons and have a gross vehicle weight rating (GVWR), which is the manufacturer specified loaded weight, of 4536 kg (10,001 pounds) or more. Passenger capacity can be increased by adding more seats, without changing either the length or width of the bus.

The AASHTO single unit truck (SU) or the single unit bus (BUS) is sometimes used as a surrogate design vehicle for school buses (see Table 1).

TABLE 1 AASHTO Single Unit Truck and Single Unit Bus

Design Vehicle	Width m (ft)	Length m (ft)	Overhang Front m (ft)	Overhang Rear m (ft)	Wheelbase m (ft)
SU	2.6 (8.5)	9.1 (30)	1.2 (4)	1.8 (6)	6.1 (20)
BUS	2.6 (8.5)	12.1 (40)	2.1 (7)	2.4 (8)	7.6 (25)

TURNING PATH METHODOLOGY REVIEW

Sources that have provided information about turning paths include several *Transportation Research Record* (TRR) articles, which mostly cover methodology. Three types of methods have been used to determine the turning path and offtracking of vehicles. The first type, field observations, involves observing actual vehicles performing turning maneuvers and determining the vehicle's path. The second method makes use of mathematical formulae, which have been developed to approximate existing vehicle turning data. The third type, model simulation, was developed to be more expedient than testing with actual vehicles. Model simulations have been performed with scale models, hand-drafted models, modeling tools such as the Tractrix Integrator, computers, and templates.

A recent study published in the *ITE Journal* concerning reversing tractor-trailer combinations used many methods to determine turning paths *(Schuster and Terry)*. According to one of the authors of the article, full-scale testing of the vehicles was performed and scale drawings of the test facilities and surrounding area were used to determine the vehicle's path. Chalk was used to mark some of the tractor-trailer's paths and the locations of these paths were determined by measuring to known objects in the surrounding area. Additionally, some of the movements were video-taped and later used to determine the physical dimensions of the vehicles.

Observational Methods

One observational method, full-scale testing, involves observing a vehicle under defined test conditions in a controlled testing environment, such as the Society of Automotive Engineers field testing procedure described in the following. Another type involves observing vehicle positions in actual on-the-road operations by means of ground-based and overhead cameras.

The earliest offtracking research used full-scale testing of actual vehicles. Early tests were run on test track curves with a known radius *(Heald)*. More recently, the Society of Automotive Engineers (SAE) has developed a field testing procedure to determine a vehicle's turning radius *(SAE)*. The method consists of the following steps.

1. Check steering geometry alignment and correct, if necessary.
2. Check the front wheel cut angles to manufacturers' recommendations. Wheel stops should be set that the minimum interference is 20 mm; or, so that with the wheel stops in contact, a margin of a quarter turn of the steering wheel is left before maximum travel of the steering gear is reached. In some cases, tire interference will be the limiting factor and in others, the steering gear travel will limit the maximum cut angle.
3. Load the vehicle to the maximum recommended gross weight.
4. Run the vehicle on a dry, flat apron, making turns in both directions in low gear at engine idle speed. The wheels should be turned to the maximum cut angle. At least two complete circles should be made before making measurements. The path of the outside wheel is marked on the pavement by pouring water on the tire while making the complete circle.
5. To determine the turning diameter, measure from the midpoint of tire contact trace on the pavement to a similar point across the diameter of the trace. Turning radius will be half this distance, and the turning center will be at the midpoint of the diameter.
6. To determine the curb clearance increment, place a straight edge horizontally across the outside face of the tire at an elevation of 150 mm above the pavement surface, and with a plumb line, locate the point on the pavement directly beneath the foremost point of contact between the straight edge and the tire shoulder. The distance from this point to the turning center is the curb clearance radius, and the difference between it and the turning radius is the curb clearance increment.
7. To determine the turning diameter, wall-to-wall, drop a plumb line from the extreme outside radial extension of the vehicle and locate the point on the pavement directly beneath it. The distance from this point to the turning center is the vehicle clearance radius. The turning diameter, wall-to-wall, is twice the vehicle clearance radius.

Mathematical Formulation

With the accumulation of data from early vehicle offtracking research, equations were developed to approximate a vehicle's turning path. Two of the equations developed are presented below. The first is one of the more common equations to determine offtracking and was developed by the Society of Automotive Engineers (SAE). The second equation was developed by the Western Highway Institute (WHI) and is intended to be an approximation of the SAE equation.

Society of Automotive Engineers (SAE) Equation

The SAE developed an equation to determine offtracking which first appeared in the 1954 Society of Automotive Engineers Handbook *(Miller and Walton)*. The SAE equation for single unit (SU) vehicles is:

$$OT = \{WB^2 + \{[(TR^2 - WB^2)^{1/2}] - HT\}^2\}^{1/2} - [(TR^2 - WB^2)^{1/2}] + HT$$

where:

OT = offtracking

WB = wheelbase

HT = front wheel track / 2, and

TR = turning radius of outside wheel.

Through the 1972 issue of the Society of Automotive Engineers Handbook, this equation was presented and was well explained. However, beginning in 1973, much of the explanation was dropped *(Heald)* and the 1995 edition of the SAE Handbook does not include the equation and states that a "new method was developed by the Western Highway Institute and a detailed discussion is presented in Research Committee Report No. 3 `Off Tracking Characteristics of Trucks and Truck Combinations'."

Western Highway Institute (WHI) Equation

The Western Highway Institute (WHI) developed an equation that approximates the SAE equation *(Heald, Miller and Walton)*. The general form of the WHI equation is:

$$OT_{max/ss} = R - (R^2 - SUM(L)^2)^{1/2}$$

where:

$OT_{max/ss}$ = maximum offtracking

R = radius of the curve followed by the front axle center, and

$SUM(L)^2$ = sum of the squares of axle spacings.

The WHI formula relates the offtracking to the center of the axles. As defined, the turning radius used in offtracking computation is the alignment path of the outer front tire at its center point. Therefore:

$$R = TR - HT$$

where:

TR = centerline of the outer front tire

HT = one-half of the front axle track (half-track).

However, both of these equations become ineffective if the rear axle tracks to the inside of the center of the curve, such as on short-radius curves *(Fong and Chenu)*.

Model Simulation

Tests using scale-models of vehicles proved to be easier and more expedient than full-scale testing with actual vehicles *(Heald)*. This testing led to the development of methods which will be discussed later, including turning templates and many of the early modeling tools, such as the Tractrix Integrator.

Many of the hand-drafting methods developed utilized the concept of representing an axle as a single point, usually the center-point of the axle. Among these methods are the bicycle model *(Sayers)*, the airplane graphical method *(Horonjeff and McKelvey)*, and the SAE Handbook method *(SAE)*. Design templates have been used to estimate offtracking requirements for the design of intersections or other facilities *(Sayers)*. A template typically consists of tracings of a vehicle's turning path at a certain scale and often includes the path of 30°, 60°, 90°, 120°, 150°, and 180° turns. Among the most common template sets are the AASHTO templates and the Jack Leisch templates.

Tools were developed which could be used to produce vehicle path curves, the most common being the Tractrix Integrator *(Heald, Millar and Walton, Fong and Chenu, Sayers)*. The device consists of a scaled bar supported at one end by a pointer and steadying frame. At the other end is an inked wheel the makes a trail of ink as the bar is moved. To use the device, the distance between the pointer and the bar is adjusted to the desired scale (representing the distance between the front and rear axles). The pointer is moved over a fixed path (representing the path of the vehicle's front axle). The ink trail left by the wheel represents the path of the rear axle of the vehicle.

More recently, computers have been used to simulate vehicle turning paths. The University of Michigan Transportation Research Institute (UMTRI) developed one of the first turning vehicle computer simulations, which was originally written for the Apple II computer *(Fond and Chenu, Carrasco)*. The California Department of Transportation (Caltrans) had started to develop an offtracking model when the agency learned of the UMTRI model *(Fong and Chenu)*, and then decided to adapt the simulation portion of the UMTRI model to produce the Truck Offtracking Model (TOM) *(Carrasco)*. The British Columbia Ministry of Transportation and Highways developed a PC DOS-based program called "TRACKER" *(Carrasco)*.

The AutoTURN program is a computer-aided design and drafting (CADD) based model, written in the C programming language, to be used in conjunction with the AutoCAD or Microstation drafting programs *(Carrasco)*. The program allows the vehicle path to be input directly into the CADD platform. One capability of the program is the ability to trace any given point on a vehicle as it traverses a specified path.

The use of the program is fairly easy and consists of these seven basic steps.

1. *Select Design Base*. The designer will select the design base, a drawing showing the layout of a

facility or roadway in which the desired vehicle path will be drawn, in AutoCAD, or Microstation.

2. *Draw Vehicle Path.* The designer draws in the desired vehicle path, which is to be followed by the center of the front axle of the vehicle.
3. *Load AutoTURN.* The AutoTURN program is loaded by selecting the Load AutoTURN command from the AutoTURN pull-down menu.
4. *Set Configuration Menu.* The configuration menu is used to select the type of vehicle, the vehicle's start position, type of simulation (tracking or swept path), type of output files desired, drawing layering, and dimension units desired.
5. *Run Simulation.* The program is run by selecting the Run Simulation option from the pull-down menu. The user will be asked to select the steering path entities in the order and direction of travel.
6. *Evaluate Vehicle Path.* The user can evaluate the vehicle path to determine conflicts with curbs, utility poles, etc. If conflicts exist, the user can modify the path or consider moving the conflicting element.
7. *Prepare Drawings.* Once an acceptable path is determined, drawings can be produced without leaving the AutoCAD or Microstation program.

CHAPTER 3

DATA COLLECTION AND DATA PLOTTING PROCEDURES

This chapter discusses the steps to complete the measurement of turning paths, which includes the use of surveys to identify design vehicles, the process to find design vehicles in the area, and the field testing and measurement procedures.

SURVEYS TO IDENTIFY DESIGN VEHICLES

Surveys were sent to three groups, each having a different perspective on school bus issues. The three groups surveyed were:

1. state transportation agencies,
2. school bus operators, and
3. school bus manufacturers.

The purposes of the surveys were to identify existing geometric design information for school buses, to identify common school bus sizes, and to select school bus design-vehicle candidates.

Survey of State Transportation Agencies

A survey of the fifty states' and Puerto Rico's departments of transportation was made to inquire about any existing geometric design information for school buses. States were asked if they:

1. had any geometric data for "full-size" school bus design vehicles,
2. made use of attributes of another design vehicle to "come close to" an actual school bus, and
3. made use of any software or other means to generate school bus vehicle turning paths.

Forty responses to the survey were received. Three states each sent back two responses. The positive responses for the first inquiry are as follows.

1. Use the state's highway design manual. Vehicles are equivalent to AASHTO's SU and BUS.
2. For an 84 passenger school bus: length = 39'-10"; width = 96"; wheelbase = 237"; front overhang = 84"; rear overhang = 151".
3. For a 70 passenger school bus making a 90° turn: outside radius = 41'.
4. Use the following dimensions for school bus design vehicle: length = 40.0'; width = 8.5'; wheelbase = 25.0'; front overhang = 7.0'; rear overhang = 8.0'.
5. For a 65 passenger conventional school bus, use the following dimensions for design vehicle: length = 408"; width = 96"; wheelbase = 254"; outer radius = 37'-07"; inner radius = 27'-00".

6. Use dimensions from *Architectural Graphic Standards, 9th Edition (AIA)*: length = 39'-06"; width = 8'-00"; rear overhang = 12'-08"; outer radius = 43'-06"; inner radius = 26'-00".
7. Use the following dimensions for school bus design vehicle: length = 40'; width = 8'; rear overhang = 14'; outer radius = 44'.
8. Use a 1995 model 78 passenger school bus with the following dimensions: length = 442"; width = 96.5"; wheelbase = 238"; curb-to-curb radius = 36'; wall-to-wall radius = 40'.

In response to the second inquiry, twenty-six use the BUS design vehicle from the *Green Book* exclusively, one uses the SU design vehicle from the *Green Book* exclusively, one uses a combination of BUS and SU design vehicle characteristics, one uses a combination of BUS and WB-50 design vehicle characteristics, one uses an SU design vehicle characteristics but designs intersections for a WB-50 design vehicle, and one state uses a design vehicle from their highway design manual, which is equivalent to the BUS design vehicle. The total number of agencies using each is as follows: BUS, 27; SU, 1; and Other, 3.

In response to the third inquiry, ten stated that the AutoTURN computer model is used exclusively, one uses both AutoTURN and the Truck Offtracking Model (TOM) computer models, three use various turning templates, and one uses both AutoTURN and a Vehicle Offtracking Program developed by the state's department of transportation. The total number of agencies using each is as follows: Turning Templates, 3; AutoTURN, 10; and Other Computer Simulations, 2.

Survey of School Bus Operators

To identify the school bus sizes commonly used, several of the larger school districts and private bus contractors in the nation were contacted. They were asked what the largest sizes (number of passengers) and types (C or D) of school buses normally used were, and which companies manufactured them.

School district transportation personnel supplied 11 responses, and 6 responses came from large regional private transportation contractors. Many of the districts and contractors gave reasons for using a particular size school bus. The responses are summarized in Table 2, which does not include the responses of two of the private transportation contractors who operate in many regions of the country.

TABLE 2 School Bus Sizes in Current Use

	Number of Passengers		
	60-69	70-79	80-89
East of Mississippi R., North of Ohio-Potomac R.	4	1	0
East of Mississippi R., South of Ohio-Potomac R.	2	2	0
West of Mississippi R.	1	1	4

The survey suggests that larger urban districts in the northeast use the smallest bus sizes, larger southeast urban districts use small to mid-size buses, and larger west urban areas use the larger buses. Small-town or rural school districts typically have longer routes and therefore may use larger buses. However, for very small rural districts, smaller school bus sizes may be preferred.

From the information collected, two bus sizes, 65/66 passenger and 83/84 passenger, were identified as the most common, and appropriate for establishing design vehicles that would be applicable for many parts of the United States.

Northeast

Several reasons were given for the sizes of buses used. Three districts in the northeast stated that street limitations were a major factor. One district noted that cars parked along the streets and narrow side streets made turning movements of larger buses a problem. Another district noted that it is difficult for larger buses to maneuver the streets, especially in winter weather.

The limited length of routes, along with frequent stops was another popular reason given for using smaller buses. Due to short routes, districts expressed concern that larger buses could not be filled to capacity and therefore were not cost effective. Also, districts noted that the frequent stops made larger buses economically unfeasible. Other reasons listed for using smaller buses included financial limitations, limitations of existing maintenance facilities which could not accommodate larger buses, and compliance with existing state standards.

The district which uses buses in the 70-79 passenger range noted that these buses comprise less than 10% of their fleet. The remainder are mostly in the 60-69 passenger range. Of the five responses, four specifically noted that there were no plans to use larger buses in the future.

Southeast

Among the responses from the southeast, the inability of the repair shop to handle larger buses was the only reason specifically noted for the size of buses chosen. However, one of the school districts using buses in the 60-69 passenger range stated that some 70-79 passenger buses had been ordered to test the effectiveness of this size bus. The school district also mentioned that longer buses were used many years ago, but they had experienced mechanical and maintenance problems.

West

While most of the responses from the west indicated the use of buses in the 80-89 passenger range, buses in the 60-69 passenger range and the 70-79 passenger range were used in one district each. The district that uses 60-69 passenger buses noted that these buses were used on regular routes, but the district had some larger buses which were used for special trips. The district also noted that there would not be a need to go to larger buses in the future.

The school district that uses mainly 70-79 passenger buses noted that the district had a few buses in the 80-89 passenger range. The district also mentioned that more students can be served with a larger bus, which is more economical.

One of the districts in the 80-89 passenger range mentioned that this was expected to be the largest size used for a while. One of the private bus contractors which use mainly 80-89 passenger buses stated that the company did not foresee using larger buses.

National Contractors

Two national contractors, not included in the preceding table, noted that 80-89 passenger buses are the largest used. However, smaller buses are also common. One of the contractors noted that more bids are being made for larger buses.

Survey of School Bus Manufacturers

To select design-vehicle candidates, the four large bus body manufacturers (Amtran, Bluebird, Carpenter, and Thomas) were contacted to inquire about specifications for the largest commonly used school buses that had been identified from the survey of school bus operators.

Each bus manufacturer was asked to provide information about the physical and operating characteristics of their 65/66 passenger type C, 65/66 passenger type D, and 83/84 passenger type D. The physical characteristics include the loaded weight, maximum height, width, overall length, wheelbase, and front and rear overhangs. The heights of roof mounted accessories (strobe lights, luggage racks, hatches/vents, and air conditioners) were also obtained. The operating characteristics include the inside tire radius, outside tire curb clearance radius, outside body sweep radius, and the vehicle turning angle.

After receiving initial responses to the survey, tables containing the specification information were resubmitted to the manufacturers for confirmation. Appendix A lists the confirmed school bus specifications. To give a degree of anonymity to them, the school bus manufacturers were designated by the letters W, X, Y, and Z, in no particular order.

Selecting Design Vehicles

From among all of the bus body and operating dimensions submitted by the four manufacturers, those bus models having the controlling design characteristics were chosen as potential design-vehicle candidates.

Controlling characteristics include overall length, wheelbase, front overhang, rear overhang, and width. After reviewing the data submitted by the school bus manufacturers, it was concluded that for the 65/66 and the 83/84 passenger school buses, those models having the larger or controlling dimensions were:

1. a 65/66 passenger type C from manufacturer X,
2. a 65/66 passenger type D from manufacturer X, and
3. an 83/84 passenger type D from manufacturer W or Z.

Table 3 lists the characteristics for these buses. The turn angle given is defined as the angle of the tires in a turning movement measured from straight ahead.

TABLE 3 Manufacturer Specified Design Vehicle Dimensions

CATEGORY	X-66C	X-66D	W-84D	Z-84D
MAXIMUM HEIGHT* m (ft)	3.05±0.08 (10.00±0.25)	2.90,3.15 (9.50,10.33)	3.29 (10.80)	3.28 (10.50)
BODY WIDTH m (ft)	2.44 (8.00)	2.44 (8.00)	2.44 (8.00)	2.44 (8.00)
OVERALL LENGTH m (ft)	10.86 (35.63)	10.15 (33.31)	12.12 (39.75)	12.07 (39.59)
FRONT OVERHANG m (ft)	0.83 (2.73)	2.07 (6.78)	2.06 (6.75)	2.10 (6.90)
WHEELBASE m (ft)	6.57 (21.56)	4.95 (16.25)	7.01 (23.00)	7.03 (23.08)
REAR OVERHANG m (ft)	3.57 (11.70)	3.13 (10.28)	3.05 (10.00)	2.93 (9.62)
INSIDE TIRE RADIUS m (ft)	5.79 (19.00)	5.90 (19.37)	9.75 (32.00)	6.73 (22.07)
OUTSIDE TIRE CURB CLEARANCE RADIUS m (ft)	11.84 (38.85)	9.97 (32.70)	11.40 (39.00)	10.90 (37.41)
OUTSIDE BODY SWEEP RADIUS, m (ft)	13.21 (43.35)	11.28 (37.00)	13.11 (43.00)	12.92 (42.40)
TURN ANGLE	50.0°	41.0°	45.0°	45.0°

* Roof mounted accessories can add to total height as follows:
small strobe light - 0.06 m (2.50 in)
large strobe light - 0.11 m (4.25 in)
luggage rack - 0.38 m (15.00 in)
hatch/vent - 0.08 m (3.00 in)
air conditioner - 0.46 m (1.50 ft)

The dimensions of the 65/66 passenger type C and 65/66 passenger type D were compared. Most attributes of the 65/66 passenger type C were either similar to or more severe than those for the 65/66 passenger type D school buses. Therefore, the researchers concentrated on two design vehicles, the 65/66 passenger type C, and the 83/84 passenger type D.

PROCESS TO FIND DESIGN VEHICLES

With the design school buses selected, the next step was locating school districts in the area which had school buses with dimensions close to those of the design buses (i.e., the 65/66 passenger type C and the 83/84 passenger type D). Twenty-one school districts in northwestern Arkansas and three in northeastern Oklahoma were contacted to inquire about any buses owned which would match the design buses selected. Of the schools contacted, three had an 83/84 passenger type D from manufacturer W, one had an 83/84 passenger type D from manufacturer Z, and four had a 65/66 passenger type C from manufacturer X.

Inspection trips were made to seven school districts. The purpose of these trips was to confirm the dimensions of the eight matching school buses, and assess the suitability of those identified vehicles for actual turning path field testing. The researchers determined that the 65/66 passenger buses had rear overhangs 0.51 m (1 ft 8 in) shorter than expected, with overall lengths that were 0.61 m (2 ft 0 in) shorter than expected. The wheelbases were 0.1 m (0 ft 4 in) shorter than expected, with front overhangs 0.07 m (0 ft 3 in) shorter than expected.

All of the 83/84 passenger buses measured had wheelbases between 1.12 m (3 ft 8 in) and 1.22 m (4 ft 0 in) shorter than expected, and rear overhangs between 0.81 m (2 ft 8 in) and 1.30 m (4 ft 3 in) longer than expected. After discussion with school transportation personnel at one school district, it was revealed that the school district had an 89 passenger school bus with dimensions similar to those of the 83/84 passenger buses. The 89 passenger school bus had the expected wheelbase and was within 0.05 m (0 ft 2 in) of the overall length of the 83/84 passenger school bus design vehicle dimensions.

BUSES SELECTED FOR TURNING PATH MEASUREMENT

Five buses were selected for field testing to measure actual turning path dimensions. Two of the buses were 65/66 passenger type C (from Springdale Public Schools); two were 83/84 passenger type D buses (one from Fayetteville Public Schools and one from Greenwood Public Schools) with a shorter wheelbase but longer rear overhang than the manufacturer specified design vehicle; and one was an 89 passenger bus (from Greenwood Public Schools) with dimensions similar to the manufacturer specified design vehicle's wheelbase and rear overhang for 83/84 passenger buses. Table 4 lists the selected vehicles with the manufacturers' specifications.

TABLE 4 Design Vehicle Dimensions and Tested Vehicle Dimensions

CATEGORY	X-66C	X-66C		W-84D	Z-84D	W-84D	Z-84D	Z-89D
	Mfg.	Spgdle1	Spgdle2	Mfg.	Mfg.	Fay.	Grnwd1	Grnwd2
BODY WIDTH	2.44	2.36	2.36	2.44	2.44	2.36	2.44	2.44
m (ft)	(8.00)	(7.75)	(7.75)	(8.00)	(8.00)	(7.75)	(8.00)	(8.00)
OVERALL LENGTH	10.86	10.90*	10.90*	12.12	12.07	12.12	12.27	12.10
m (ft)	(35.63)	(35.75)*	(35.75)*	(39.75)	(39.59)	(39.75)	(40.25)	(39.63)
FRONT OVERHANG	0.83	0.76	0.76	2.06	2.10	2.44	2.13	2.13
m (ft)	(2.73)	(2.50)	(2.50)	(6.75)	(6.90)	(8.00)	(7.00)	(7.00)
WHEELBASE	6.57	6.48	6.48	7.01	7.03	5.79	5.92	7.01
m (ft)	(21.56)	(21.25)	(21.25)	(23.00)	(23.08)	(19.00)	(19.42)	(23.00)
REAR OVERHANG	3.57	3.66*	3.66*	3.05	2.93	3.89	4.22	2.94
m (ft)	(11.70)	(12.00)*	(12.00)*	(10.00)	(9.62)	(12.75)	(13.83)	(9.63)
INSIDE TIRE RADIUS	5.79	10.15	7.65	9.75	6.73	6.65	6.38	7.71
m (ft)	(19.00)	(33.31)	(25.10)	(32.00)	(22.07)	(21.83)	(20.92)	(25.31)
OUTSIDE TIRE CURB	11.84	13.95	11.80	11.89	11.40	10.90	11.07	12.13
CLEARANCE RADIUS, m (ft)	(38.85)	(45.78)	(38.73)	(39.00)	(37.41)	(35.77)	(36.31)	(39.78)
OUTSIDE BODY	13.21	14.39	12.29	13.11	12.92	12.43	12.36	13.45
SWEEP RADIUS, m (ft)	(43.35)	(47.21)	(40.31)	(43.00)	(42.40)	(40.78)	(40.54)	(44.11)
TURN ANGLE	50.0°	36.9°	31.3°	45.0°	45.0°	N/A	45.3°	45.8°

* With rear extension bar

TURNING PATH FIELD MEASUREMENTS

For the tests, the center aisle of each school bus was loaded with 40 sand bags weighing 31.8 kg (70 lbs) each (total of 1270 kg) to simulate a passenger load. The sand bags (see Figure 1) were wrapped in a plastic wrap to prevent spilling or breaking. The turning tests were performed in a large, fairly level concrete parking lot. The tests were performed when the parking lot surface was dry.

To determine the turning radii and swept path of the school buses, four positions on the bus were measured as the bus made 90° and 180° turns to the right:

1. the left (outer) front corner,
2. the left (outer) rear corner,
3. the left (outer) front tire, and
4. the right (inner) rear tire.

To mark the paths of the left front and left rear corners as the bus turned, magnets with attached X-clamps were attached to the corners of the bumpers. The X-clamps were to hold burettes. However, this configuration proved too heavy for the magnets to hold. Therefore, C-clamps were attached to the corners of the bumpers, then X-clamps were attached to the C-clamps. The X-clamps held burettes filled with a water-soluble crayon-paste paint. Just before each test began, valves at the bottom of the burettes were opened, allowing the paint to drain from the burette (see Figure 2). As the bus made its turn, the burette deposited a thin paint trail on the ground.

To mark the outer front and inner rear tire paths, pump-up water tanks were placed inside the bus. Hoses extended from these tanks, through open windows, to sprayers clamped to the tire-well, directly above the axle. The water was sprayed on the outer tread of the tire. When the bus made a turn, the wet tread left a path on the concrete. To enhance the quality of the wet tread marks, the tire surfaces were well-wetted before the tests began. Since the water would evaporate quickly, four people immediately marked the resulting water path with colored lumber crayons or sidewalk chalk upon completion of each test turn.

For the test of the type C school bus, an extension bar was added to the rear of the vehicle to simulate the length of the manufacturer-specified vehicle. The extension bar was clamped to the left side of the bus with C-clamps. A stabilizing bar was clamped to the rear bumper of the bus and butted up against the extension bar to help hold it in place. A C-clamp was attached to the extension bar. An x-clamp was attached to the C-clamp and held the burette filled with the water-soluble paint.

During the school bus turning tests, the bus drivers were instructed to make a right turn as sharp as safely possible while keeping the bus speed less than 16 km/hr (10 mph). One person from the research team was in the school bus to help the driver monitor speed; this allowed the driver to concentrate on making the turn without having to watch the speedometer. As the turn was made, another individual timed

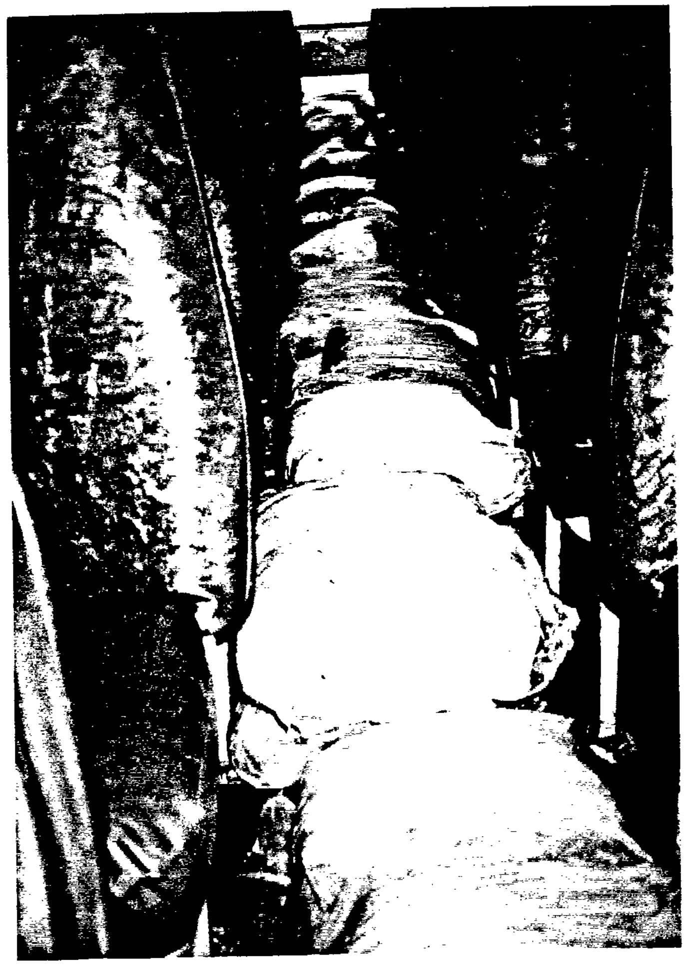

FIGURE 1 Sand Bags Simulating Loaded Weight

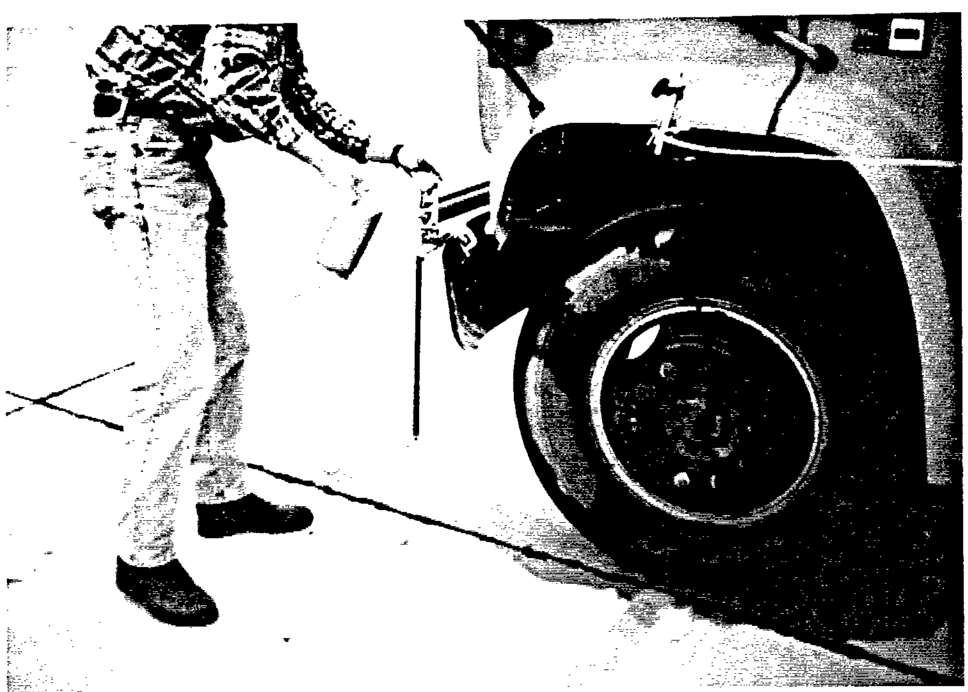

FIGURE 2 Burettes on Bus Body and Tire Water Spraying Apparatus

PLOTTING THE FIELD DATA

The measured points were manually entered into the AutoCAD drafting program. The turning paths were drawn by connecting the points using the "spline" function, which fits a smooth curve to the turning path data points.

For each plotted 180° test turn, the following were found:

1. the outer front wheel radius, also known as the design radius (R);
2. the outer front body radius, also known as the maximum radius (max.); and
2. the inner rear wheel radius, also known as the minimum radius (min.).

The outer front wheel radius is defined as the (assumed) circular path of the outer front wheel. In actual vehicle operations, the vehicle wheel must follow a spiral path into a turn before beginning to follow a true circular path (arc). Therefore, the wheel does not begin to follow a circular arc until approximately 1/4 of the way through the turn. The outer front body radius is defined as the circular path of the outer front overhang. Again, the circular path is not found until part-way through the curve because of the initial spiral of the turn. The inner rear wheel radius is defined as the circular path of the inside rear tire.

To find the outer front wheel, outer front body and inner rear wheel radii, analysis was made in the AutoCAD files containing the drawn turning paths. First, the outer front wheel radius was found by drawing a circle on the outer front tire path by selecting three points on the circular part of this path. The radius of this circle was found using the "list" command. Next, a point was set at the center of this circle. This point is the center point of the vehicle's turn. From this center point, two circles were drawn using a "rubber-band" cursor, which allows the user to drag each circle to the desired radius. In this case, the desired radius of the first circle was to a point which most closely matched the circular part of the outer front overhang path. The radius of the circle (which is the outer front body radius) was found using the "list" command. The desired radius of the second circle was to a point which most closely matched the circular part of the inner rear wheel path. The radius of the circle (which is the inner wheel radius) was found using the "list" command.

COMPARISON WITH OTHER METHODS

The turning paths found during field testing were compared with other commonly-used paths, such as the AASHTO design vehicles, the AutoTURN computer simulation program output, and the Airplane Graphical Method output.

The comparisons of the field test drawings with AASHTO's SU and BUS design vehicle turning templates were made by overlaying them on a light table.

The dimensions of the school bus were entered into AutoTURN and the path of the center of the vehicle's front axle was drawn in Microstation. The simulation output the path followed by the outer front tire and the inner rear tire. The paths were then printed at a scale of 1" = 20'. Comparison was made by overlaying the field test drawing and the AutoTURN drawing on a light table.

The Airplane Graphical Method was also used to produce turns similar to the field test turns. The desired path of the center of the front axle of the vehicle was drawn with the AutoCAD drafting program. The initial positions of the axle center points were marked. The rear axle point was moved farther along the path. The front axle point was determined and marked by drawing a circle with a radius equal to the vehicle's wheelbase. This procedure was repeated until the turn was complete. The rear axle's path was drawn using the "spline" function, which fits a smooth curve to the points. The wheel paths were drawn by offsetting the axle paths by half the axle width. The paths were then printed at a scale of 1" = 20'. Comparison was made by overlaying the field test drawing and the AutoTURN drawing on a light table.

CHAPTER 4
RESULTS

During field testing of the school buses and subsequent plotting of data, many interesting effects were noticed. This chapter includes a discussion of these effects and an explanation of the test results shown in Table 5.

ADJUSTABLE WHEEL STOP

After initial tests were run (tests 1-16, Table 5) and the turns plotted, visual inspection of the plotted bus turning paths showed that the 89 passenger Z bus and the 65/66 passenger X bus had significantly larger turning radii than the two 83/84 passenger buses had. The 89 passenger bus from manufacturer Z had a 34' turning radius and the 65/66 passenger bus from manufacturer X had a 40' turning radius. Because of this, another series of tests were made on each of these two buses.

The retest of the 89 passenger bus from manufacturer Z (tests 17-20, Table 5) yielded results close to those of the initial tests. However, the retest of the 66 passenger bus from manufacturer X (tests 21-24, Table 5) produced turns that were significantly smaller than those of the initial tests. Since both X buses tested were the same make and model (with the same dimensions), bus personnel at the school district which owned the buses were contacted. The bus personnel informed the researchers that a "wheel stop" exists on the front wheels of a school bus; this wheel stop can be adjusted to change the turning angle of the buses' front wheels. Because of this, trips to the school districts owning the design vehicle buses were made to measure the existing turning angle of the tested buses.

The measurement method used provides a rough approximation of the actual turning angle. Each bus was driven into a right turn at the sharpest angle possible and stopped with the wheels turned at the maximum angle. Then, two long straight bars were used to mark a triangle on the ground. The first bar was placed in line with the bus body and the second was placed in line with the turned wheel. Paint was used to mark the triangle created, and the triangle sides were measured. The resulting angle was calculated using trigonometric functions.

The two X buses yielded angles of 31.3° and 36.9°. The second bus's wheel was almost rubbing tie rod bolts; therefore, the wheel stop could not be adjusted much more. The maximum angle listed by the manufacturer was 50.0°.

The angle of the 84 passenger Z was measured as 45.8° and the 89 passenger Z angle was 45.3° (with some further adjustment possible). The manufacturer's listed maximum steering angle was 45.0°, so the estimated angles for the 84 and 89 passenger tested buses were close to the manufacturer's listed angles.

TABLE 5 School Bus Test Results

Test	Date	School Dist.	Type, # of pass.	Bus Mfg.	Wheel-base m (ft)	Front over-hang m (ft)	Rear over-hang m (ft)	Speed km/hr	(mph)	Radius: Outer Tire m	Radius: Inner Tire m	Radius: Outer Front Corner m	Left rear kick-out, beginning of turn m
1	9/5/96	Fay.	D,	W	5.79	2.44	3.89	14.8	(9.2)				0.49
2			83/84		(19.00)	(8.00)	(12.75)	13.7	(8.5)	10.32	6.47	12.00	0.44
3								13.4	(8.3)	10.90	6.65	12.43	0.38
4								no data					
5	10/15/96	Spgd.	C	X	6.48	0.76	3.66*	7.2	(4.5)				0.69
6			65/66		(21.25)	(2.50)	(12.00)*	9.3	(5.8)				0.46
7								11.7	(7.3)	13.95	10.15	14.39	0.41
8								12.1	(7.5)	13.86	9.94	14.00	0.45
9	11/7/96	Grnwd.	D	Z	7.01	2.13	2.94	14.6	(9.1)				0.19
10			89		(23.00)	(7.00)	(9.63)	14.8	(9.2)				0.15
11								11.1	(6.9)	12.89	7.71	13.99	0.13
12								11.7	(7.3)	12.66	7.42	14.08	0.11
13	11/8/96	Grnwd.	D	Z	5.92	2.13	4.22	11.3	(7.0)	11.07	6.38	12.36	0.57
14			83/84		(19.42)	(7.00)	(13.83)	14.8	(9.2)	10.84	6.85	12.22	0.40
15								12.4	(7.7)				0.51
16								9.7	(6.0)				0.47
17	3/27/97	Grnwd.	D	Z	7.01	2.13	2.94	11.6	(7.2)				0.18
18			89		(23.00)	(7.00)	(9.66)	10.6	(6.6)	12.61	8.21	13.94	0.18
19								10.6	(6.6)				0.12
20								10.3	(6.4)	12.13	7.71	13.45	0.21
21	4/21/97	Spgd.	C	X	6.48	0.76	3.66*	14.0	(8.7)	11.80	7.65	12.29	no data
22			65/66		(21.25)	(2.50)	(12.00)*	13.7	(8.5)	11.61	7.54	12.12	0.38
23								13.0	(8.1)	11.21	7.09	11.65	0.46
24								11.3	(7.0)	11.96	7.75	12.36	0.41

NOTES: Districts Fay. = Fayetteville, Grnwd. = Greenwood, Spgd. = Springdale
* with extension bar

SPECIAL CONSIDERATIONS

The research team members observed two attributes which bear special consideration. One is the effect of the large rear overhang that many school buses have. The other is a function of the particular driver.

"Kick-Out" Effect

Review of the plotted data indicated that the trace of the outer rear corner of the bus was a controlling factor. During the beginning of a turning maneuver, the rear corner of the vehicle would kick-out past the path or trace made by the front of the bus. This action could cause the rear of the bus to swing into the adjoining lane during a left or right turn. When making sharp turns in a parking lot or on a city street, the rear of the bus could swing into parked cars or other objects alongside the route of the bus. No previous literature on this topic was found during the literature review, and this phenomenon was not shown on other design vehicle turning templates, such as the AASHTO templates in the *Green Book*. During testing, kick-out distances were noted to be as much as 0.69 m (2.26 ft) (see Figure 4). When dealing with vehicles having large rear overhangs, the facility designer should be cognizant of this problem.

Oversteer

Also during review of the plotted paths, a "bulbing" effect, commonly known as oversteer *(Transoft)*, was observed at the end of the turn. This occurs at the end of a turn when the bus driver transitions or straightens out of a 180° turn. Instead of finishing with a circular arc, the front of the bus swings back to the inside causing a bulb shape at the end of a turn. This effect is largely determined by the way in which the driver chooses to transition out of the turn.

Figure 5, taken from one of the tests, demonstrates oversteering. Since oversteering is a function of and will vary with the vehicle operator, no attempt was made to quantify this effect during the school bus tests.

TEST RESULTS

The test results include test number and date; type and size of the bus; bus dimensions; test speeds; resulting turning radii for 180° turns; and the "kick-out" measured.

CONFIRMING SCHOOL BUS DIMENSIONS

To determine if the selected design dimension and radii were acceptable, the information was submitted to the School Bus Manufacturers Technical Committee (SBMTC) of the National Association of State

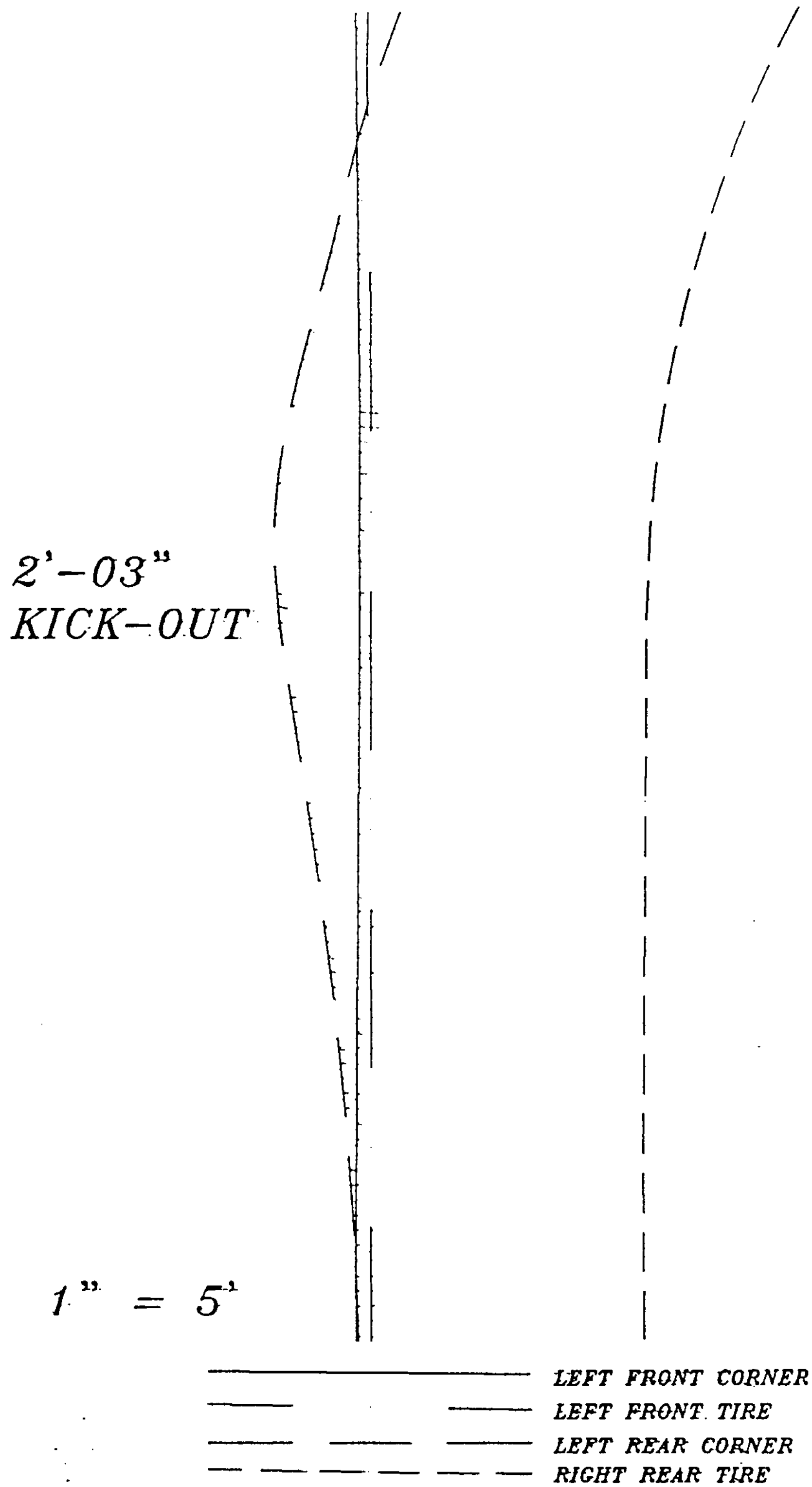

FIGURE 4 Rear Body "Kick-Out" Effect

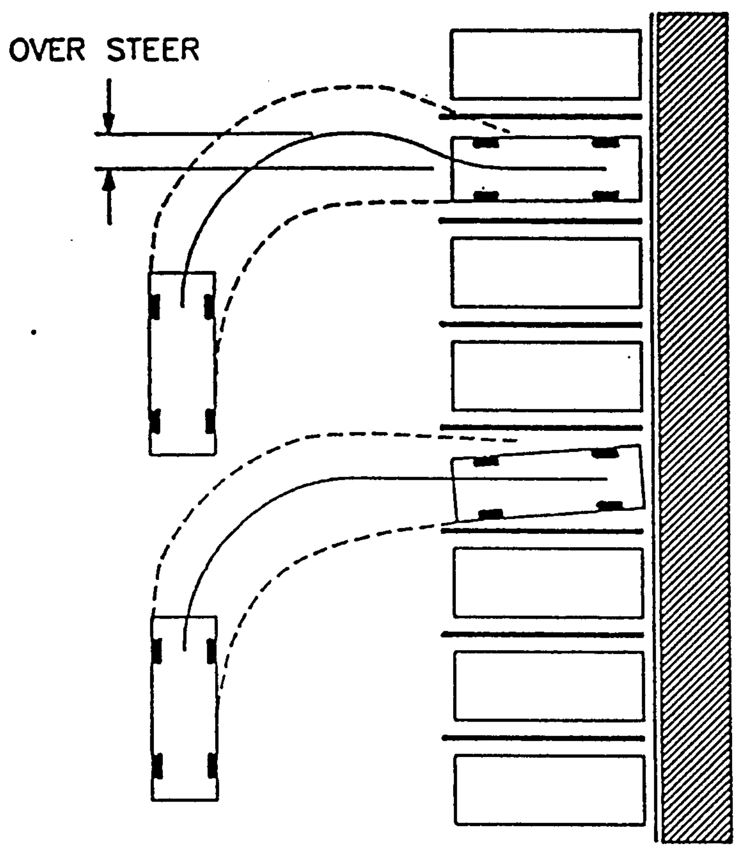

FIGURE 5 Example of Oversteer

Directors of Pupil Transportation Services. After the information was presented at an SBMTC meeting, two sets of comments were returned. In response to these comments, the following changes were made:

1. the front overhang of the type C was increased from 0.76 m (2.5 ft) to 0.85 m (2.8 ft),
2. the length of the type C was increased from 10.9 m (35.8 ft) to 11.1 m (36.4 ft),
3. the height of the type C was increased from 3.2 m (10.5 ft) to 3.3 m (10.9 ft),
4. the height of the type D was increased from 3.3 m (10.8 ft) to 3.3 m (10.9 ft), and
5. due to the effect of #1 above, the path of the left front corner of the type C was recalculated for the longer front overhang and the maximum turning radii increased from 12.3 m (40.3 ft) to 12.4 m (40.8 ft).

To accomplish change *(Heald)*, a template of the type C bus was superimposed on the drawn turning path for this bus at various points. The template was positioned by placing the right rear wheel and the left front wheel on the respective paths of the drawing. The adjustment was made by marking the position of the left front corner of the bus template with a point. After several points were marked in this fashion, the points were connected with the "spline" command. The new path drawn is the path for the left front corner of the design bus with a 0.85 m (2.8 ft) front overhang. The new maximum turning radius for this path is 12.4 m (40.8 ft).

COMPARISON WITH OTHER METHODS

To determine the validity of the test results, the plotted vehicle paths were compared to other methods. Comparisons were made with:

1. AASHTO's SU and BUS design vehicles, which are commonly used as surrogate design vehicles for school buses,
2. AutoTURN, a computer turning simulation program, which is used to produce turning templates, and,
3. the airplane graphical method, which is used to hand-draft turning templates.

AASHTO's SU and BUS Design Vehicles

Comparison of the dimensions and turning radii of the selected design vehicles (SB-C and SB-D) with AASHTO's SU and BUS is made in Table 6. Comparison was also made with the recommended templates (SB-C and SB-D) and the SU and BUS templates. Both the SB-C and the SB-D have widths of 8.0' while the SU and BUS vehicles have widths of 8.5'.

Comparisons were made by superimposing the turns on a light table with the inside (right) bus edge paths aligned at the beginning of the turn.

TABLE 6 Recommended Design Vehicles Compared with "SU" and "BUS"

		Overall		Overhang			Turning Radius of Wheel	
		Width	Length	Front	Rear	Wheelbase	Outer Front	Inner Rear
Design Vehicle Type	Symbol	m (ft)	m (ft)	m (ft)	m (ft)	m (ft)	m (ft)	m (ft)
Single Unit Truck	SU	2.6	9.1	1.2	1.8	6.1	12.8	8.5
		(8.50)	(30.00)	(4.00)	(6.00)	(20.00)	(42.00)	(27.80)
Single Unit Bus	BUS	2.6	12.1	2.1	2.4	7.6	12.8	7.4
		(8.50)	(40.00)	(7.00)	(8.00)	(25.00)	(42.00)	(24.40)
School Bus Type C	SB-C	2.44	11.08	0.85	3.66	6.48	11.84	7.67
		(8.00)	(36.40)	(2.80)	(12.00)	(21.25)	(38.87)	(25.20)
School Bus Type D	SB-D	2.44	12.18	2.44	4.22	7.01	12.18	7.68
		(8.00)	(40.00)	(8.00)	(13.83)	(23.00)	(40.00)	(25.23)

SB-C Vs. SU

The recommended SB-C outer front wheel, outer front body, and inner rear wheel radii are smaller than the SU radii. The templates show that the school bus makes a much smaller turn than the single unit truck, even though the SB-C is larger than the SU vehicle.

SB-C Vs. BUS

The recommended SB-C outer front wheel and outer front body radii are smaller than the BUS radii. The inner rear wheel radius of the SB-C is 0.8' larger than that of the BUS. During the transition portions of the turn, the BUS and SB-C have very different paths. The BUS spirals slowly into the turn, whereas the SB-C more quickly attains a circular path. The inner rear wheel paths are similar in the middle portion of the turn. The overall turn of the SB-C is much smaller. The SB-C has a shorter overall length than the BUS vehicle.

SB-D Vs. SU

The recommended SB-D outer front wheel and inner rear wheel radii are smaller than those of the SU. The outer front body radius is the same. However, due to the manner in which the SB-D transitions into and out of the curve, the overall turn is smaller than the SU turn. The SB-D has a greater overall length than the SU vehicle.

SB-D Vs. BUS

The recommended SB-D outer front wheel, inner rear wheel, and outer front body radii are smaller than those of the BUS. The overall turn of the SB-D is smaller due to the beginning and ending transitions into and out of the curve. The overall length of the SB-D is the same as the BUS vehicle.

AutoTURN

The AutoTURN turning path computer program was used to produce turns similar to those of the test turns. However, the AutoTURN-produced turns followed a circular path throughout the turns. Therefore, the AutoTURN plots do not show a "bulbing" effect. The AutoTURN plots (see Figures 6-7) were generated by assuming the beginning and ending straight away positions were the same as those found in field tests (i.e., the diameter found in the field tests was input into the AutoTURN plot). This was done to attempt to show how actual turns differed from those produced by computer simulations.

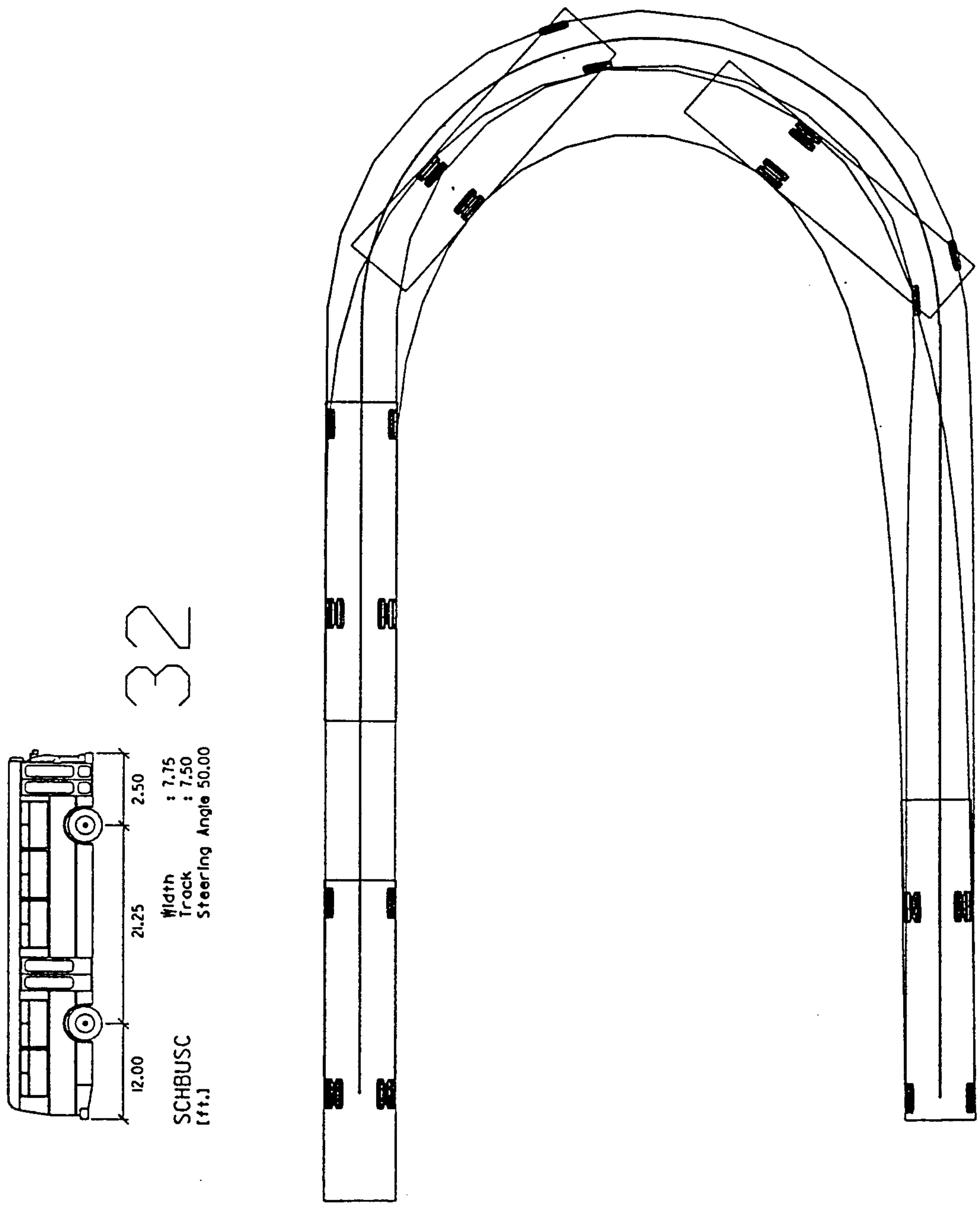

FIGURE 6 AutoTURN Produced Type "C" School Bus Turn Path

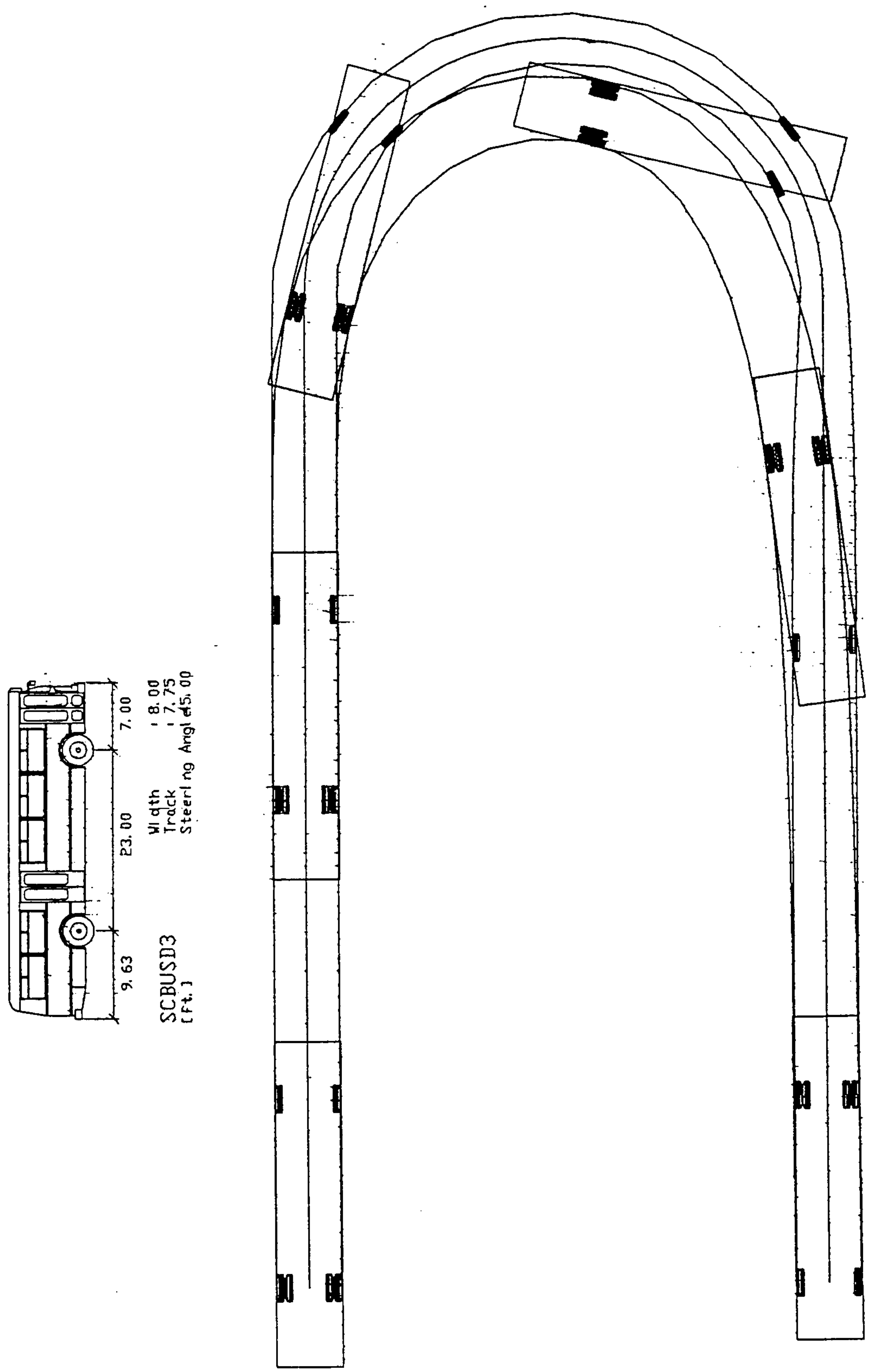

FIGURE 7 AutoTURN Produced Type "D" School Bus Turn Path

SB-C Vs. AutoTURN

The path of the SB-C design vehicle's inside tire is outside of the path shown by AutoTURN. This indicates that the AutoTURN plot has a smaller inner rear wheel radius. The outer front wheel radius paths are similar in the middle part of the turn. However, due to the circular path of the AutoTURN plot and the oversteer of the actual vehicle, the outer front wheel radius path of the SB-C is outside of the AutoTURN design radius path at the beginning and ending of the turn. The portions of the turn between 50° and 160° are similar.

SB-D Vs. AutoTURN

The path of the SB-D design vehicle's inner rear tire extended slightly farther out at the beginning and much farther out at the end of the turn than did the AutoTURN inside tire path. At the midpoint of the turn, the field-measured and the AutoTURN-produced inner rear tire radius paths almost overlap.

Due to the circular path of the AutoTURN plot and the oversteer of the actual vehicle, the design radius (outer front tire) path of the SB-D is outside of the AutoTURN design radius path at the beginning and end of the turn. In the middle of the turn, the outer front tire radius paths of both the field and the AutoTURN plots are similar.

Airplane Graphical Method

Comparisons were also made between plots of actual turns and plots from the airplane graphical method, to show how turns produced with hand-drafting methods differ from actual turns. The turns produced with this method were drawn in AutoCAD instead of pen and paper, but the procedure remains the same. (See Figures 8-9). For this procedure, a circular path was used as the designated path for the center point of the front axle. Therefore, no "bulbing" effect is present in the plots for this method.

SB-C Vs. The Airplane Graphical Method

The path of the SB-C design vehicle's inside tire is very similar to the path shown by the airplane graphical method. The outer front wheel radius paths are similar in the middle part of the turn. However, due to the circular path of the Airplane graphical method plot and the oversteer of the actual vehicle, the outer front wheel radius path of the SB-C is outside of that of the Airplane graphical method path at the beginning and ending of the turn.

SB-D Vs. The Airplane Graphical Method

The path of the SB-D design vehicle's inside tire is very close to the path shown by Airplane Graphical

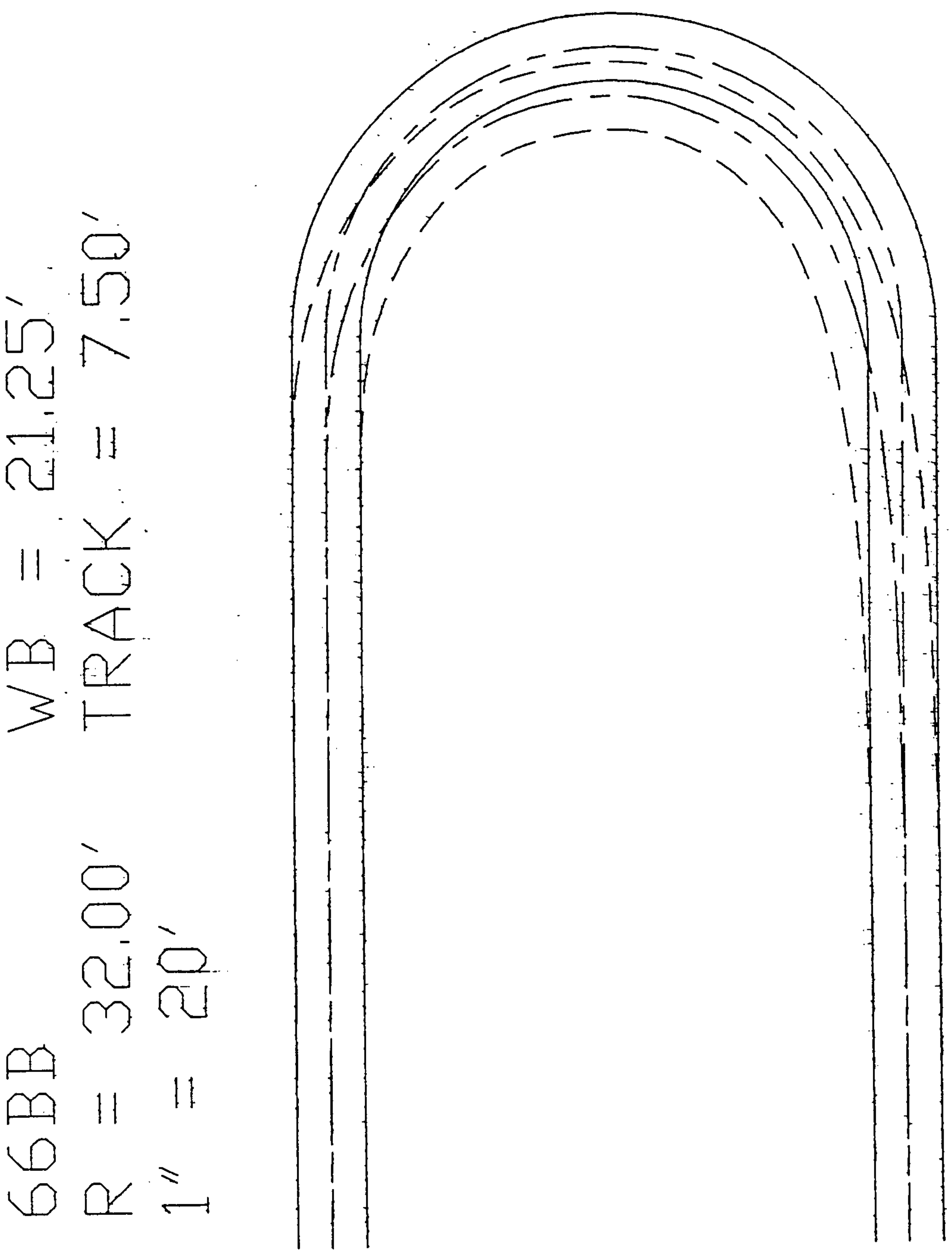

FIGURE 8 Airplane Graphical Method Type "C" School Bus Path Turn

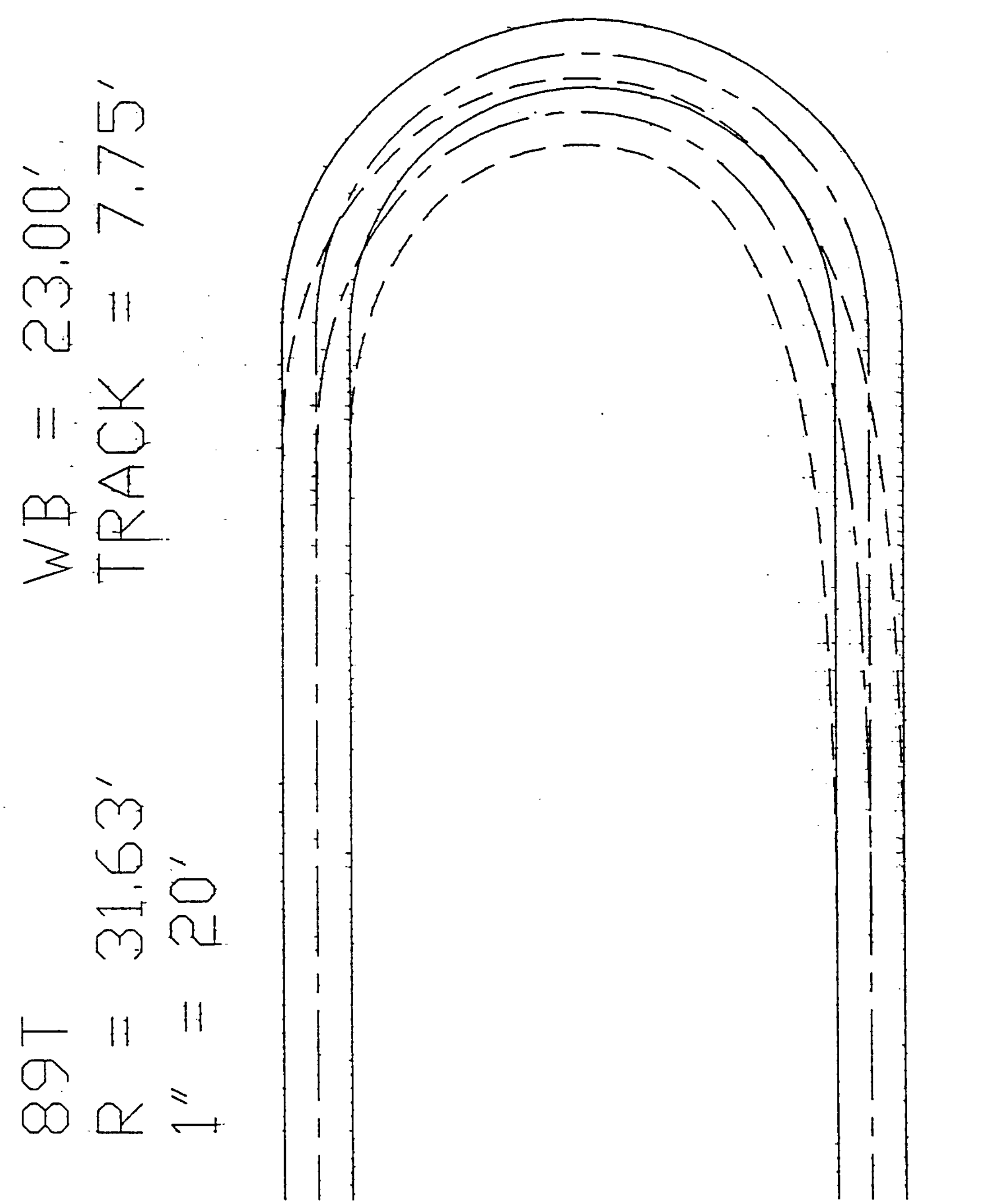

FIGURE 9 Airplane Graphical Method Type "D" School Bus Turn Path

Method through much of the turn, but is much greater at the end of the turn. The outer front wheel paths are similar in the middle part of the turn. However, due to the circular path of the Airplane graphical method plot and the oversteer of the actual vehicle, the outer front wheel radius path of the SB-D is outside of that of the Airplane graphical method path at the beginning and ending of the turn.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

From the bus manufacturers specifications and test results, the worst cases of each dimension and turning radii were combined into a hybrid design vehicle. For example, the overall length of bus "A" may be more restrictive than bus "B", while bus "B" may have a more restrictive turning radius than bus "A". Therefore, the overall length of bus "A" would be combined with the turning path of bus "B" to create the design bus. While a vehicle with all the characteristics does not actually exist, use of the worst case for each characteristic allows for the design of a facility to accommodate any bus with less restrictive characteristics. Hybrid design vehicles were developed for both type C and type D buses.

DESIGN VEHICLE FOR TYPE C SCHOOL BUSES

The recommended type C school bus design vehicle dimensions and turning radii are as follows.

Width = 2.4 m (8.0 ft)
Length = 11.1 m (36.4 ft)
Height = 3.3 m (10.9 ft)
Front Overhang = 0.85 m (2.8 ft)
Wheelbase = 6.5 m (21.3 ft)
Rear Overhang = 3.7 m (12.0 ft)
Outer Front Body Radius = 12.4 m (40.8 ft)
Outer Front Wheel Radius = 11.8 m (38.9 ft)
Inner Rear Wheel Radius = 7.7 m (25.2 ft)

Roof mounted accessories can add to total height as follows.

small strobe light - 0.06 m (2.50 in),
large strobe light - 0.11 m (4.25 in),
luggage rack - 0.38 m (15.00 in),
hatch/vent - 0.08 m (3.00 in), and
air conditioner - 0.46 m (1.50 ft).

The recommended design template can be found in Figures 10 and 11.

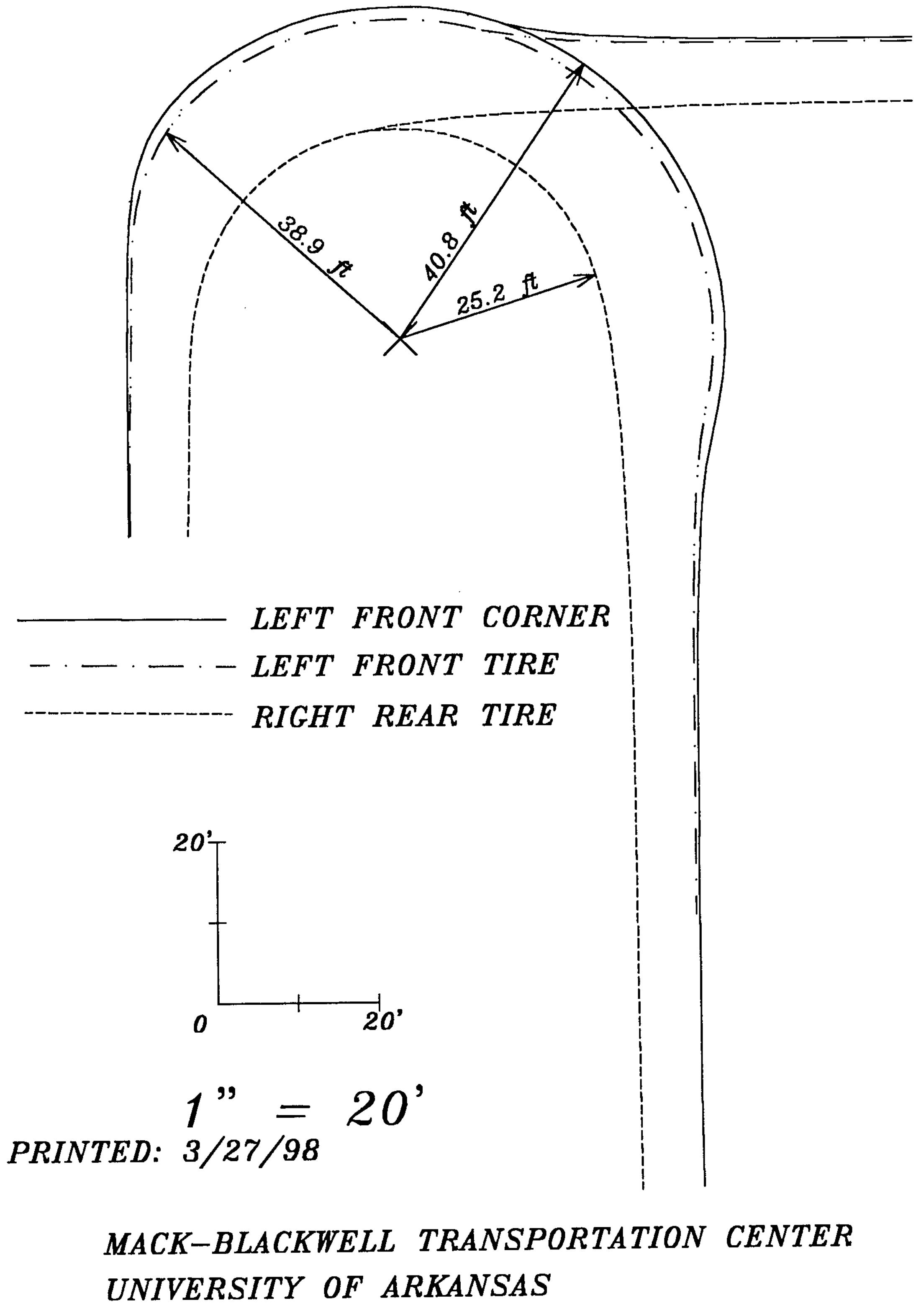

FIGURE 10 Recommended Type "C" School Bus Turning Template

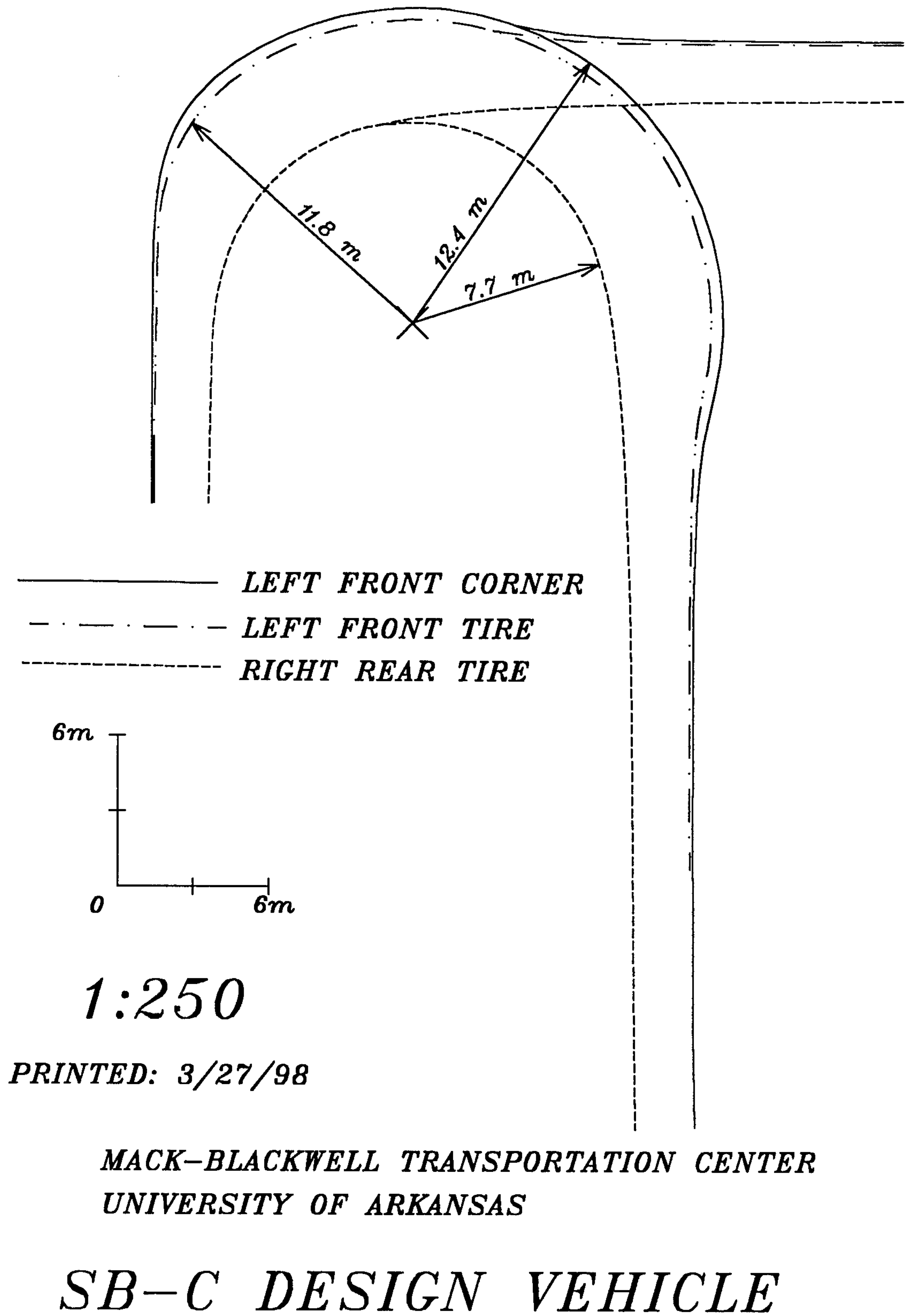

FIGURE 11 Recommended Metric Type "C" School Bus Turning Template

DESIGN VEHICLE FOR TYPE D SCHOOL BUSES

The recommended type D school bus design vehicle dimensions and turning radii are as follows.

Width = 2.4 m (8.0 ft)

Length = 12.2 m (40.0 ft)

Height = 3.3 m (10.9 ft)

Front Overhang = 2.1 m (7.0 ft)

Wheelbase = 7.0 m (23.0 ft)

Rear Overhang = 2.9 m (9.7 ft)

Outer Front Body Radius = 13.4 m (44.1 ft)

Outer Front Wheel Radius = 12.2 m (40.0 ft)

Inner Rear Wheel Radius = 7.7 m (25.2 ft)

Roof mounted accessories can add to total height as follows.

small strobe light - 0.06 m (2.50 in),

large strobe light - 0.11 m (4.25 in),

luggage rack - 0.38 m (15.00 in),

hatch/vent - 0.08 m (3.00 in), and

air conditioner - 0.46 m (1.50 ft).

The recommended design template can be found in Figures 12 and 13.

Existing national standards allow for a width of 8.5 ft (2.6 m) and a length of 40.0 ft (12.2 m) *(CMSU)*. Therefore, the possibility exists that dimensions of future buses may exceed those found in this research project

CONCLUSIONS

The comparison of the recommended school bus design vehicles (SB-C and SB-D) with AASHTO's SU and BUS vehicles showed that the school bus turn radius was less than that of the AASHTO vehicles. Therefore, using AASHTO SU or BUS vehicles as surrogate design vehicles for school buses (as several state transportation agencies do) is conservative.

Oversteering (bulbing effect) contributes to a sizeable difference between turning paths observed during actual vehicle operations and paths modeled by simulation. The models do not truly represent the ending transition of actual school bus turns because the models replicate circular paths instead of spiral paths. However, the actual turns observed during this research correlate well with the middle portions of the simulation turns and fairly well with the beginning transitions.

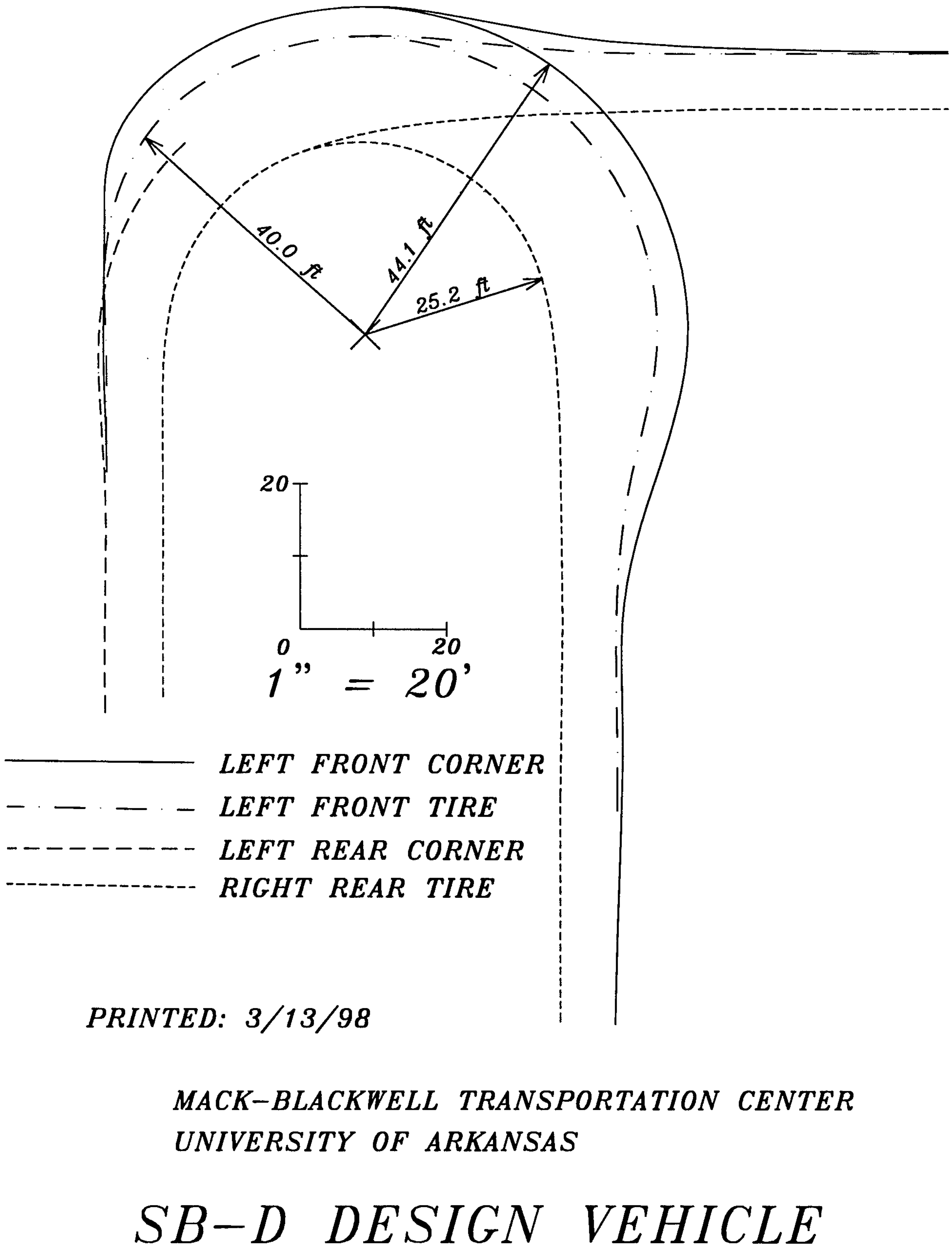

FIGURE 12 Recommended Type "D" School Bus Turning Template

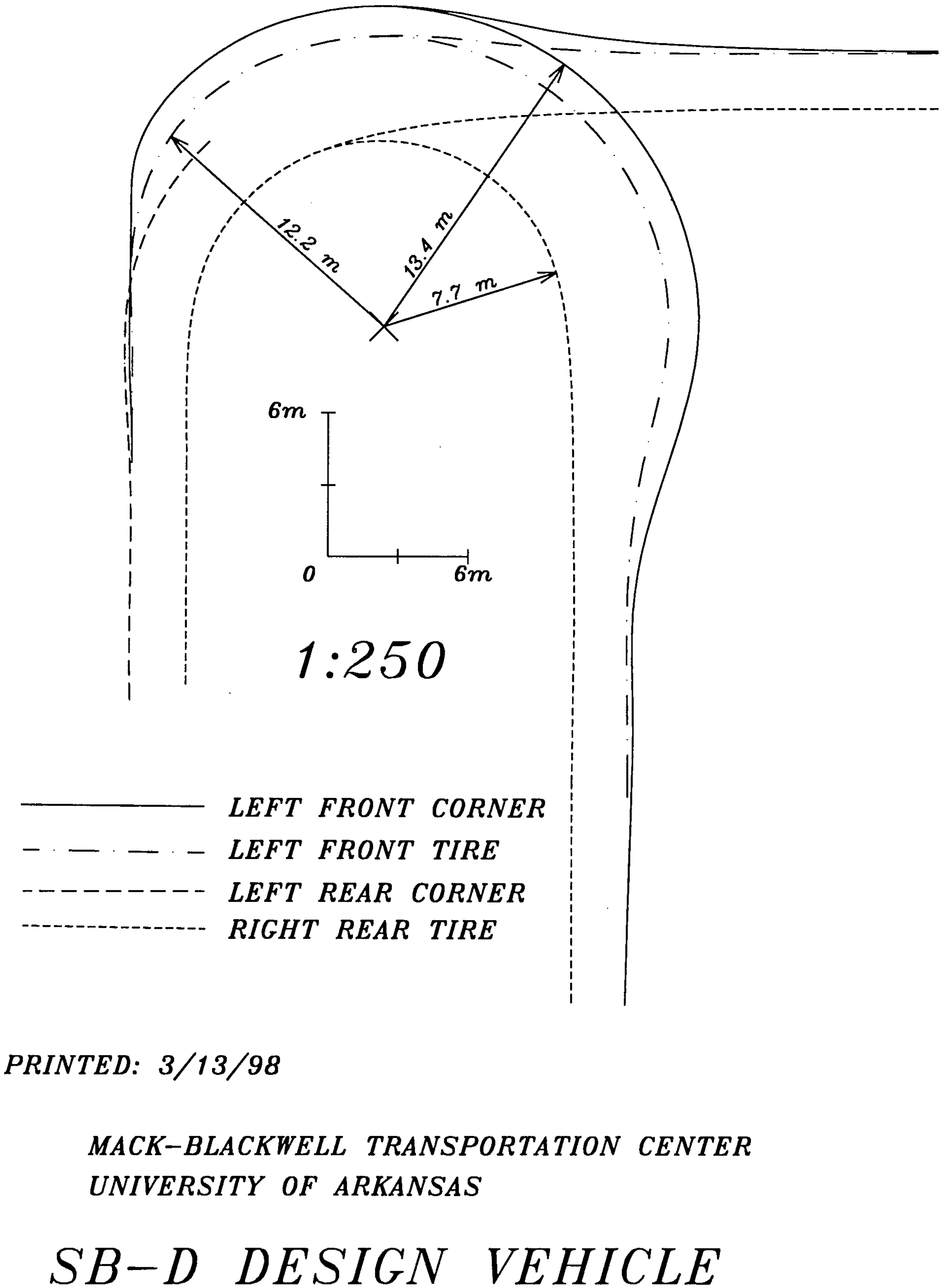

FIGURE 13 Recommended Metric Type "D" School Bus Design Template

RECOMMENDATIONS

For most of the turning path, currently accepted turning path design methods (such as computer simulation) produce a fair representation of the actual paths of the school buses observed during the field observations described herein. Current turning path templates do not present the rear kickout that the researchers observed at the beginning of a turn. The large oversteer of actual school buses can vary from driver to driver and is difficult to represent with turning path models. Computer simulations could be modified to better represent vehicle turn paths at the beginning and the end of a turn.

Since no standard school bus design vehicles or templates are in widespread use, the SB-C and SB-D school bus design vehicles and associated templates presented are recommended for use in geometric design to accommodate school buses. The authors also recommend that the profession use terms that are more obvious or intuitively descriptive, such as "outer front wheel radius" (instead of "design radius"), "outer front body radius" (instead of "maximum radius"), and "inner rear wheel radius" (instead of "minimum radius").

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APPENDIX A

TABLE A1 65/66 Passenger Type C School Bus Data

	BUS MANUFACTURER			
CATEGORY	Mfgr. W	Mfgr. X	Mfgr. Y	Mfgr. Z
LOADED WT. kg (lbs)	10,306 (22,705)	11,760 (25,907)	7,135 (15,719)	11,371 (25,050)
MAX. HEIGHT m (ft)	3.17 (10.40)	3.05±00.08 (10.00±00.25)	3.12 (10.25)	3.18 (10.42)
BODY WIDTH m (ft)	2.44 (8.00)	2.44 (8.00)	2.44 (8.00)	2.44 (8.00)
CENTER-TO-CENTER OUTER TIRE WIDTH m (ft)	2.13 (7.00)	2.18 (7.16)	*	2.42 (7.95)
OVERALL LENGTH m (ft)	10.30 (33.80)	10.86 (35.63)	11.07 (36.33)	10.68, 10.65 (34.70), (34.95)
FRONT OVERHANG m (ft)	0.82 (2.70)	0.83 (2.73)	*	0.83 (2.73)
WHEELBASE m (ft)	6.46 (21.20)	6.57 (21.56)	6.45 (21.16)	6.46 (21.17)
REAR OVERHANG m (ft)	3.02 (9.90)	3.57 (11.70)	2.79 (9.17)	3.33 (10.93)
RADIUS TO INSIDE TIRE m (ft)	8.20 (26.90)	5.79 (19.00)	*	*
OUTSIDE TIRE CURB CLEARANCE RADIUS m (ft)	10.33 (33.90)	11.84 (38.85)	*	11.10 (36.42)
OUTSIDE BODY SWEEP RADIUS m (ft)	10.70 (35.10)	13.21 (43.35)	*	11.45 (37.58)
ENGINE (SMALLEST AVAILABLE ON THIS SIZE VEHICLE)	175 HP	6.6L CAT 3116 170 HP	*	175 HP
TURN ANGLE	45.0°	50.0°	*	45.0°

* Dependent upon chassis manufacturers data
N/A = Not Available

TABLE A2 65/66 Passenger Type D School Bus Data

	BUS MANUFACTURER			
CATEGORY	Mfgr. W	Mfgr. X	Mfgr. Y	Mfgr. Z
LOADED WT. kg (lbs)	11,900 (26,216)	11,162 (24,590)	11,489 (25,311)	12,528 (27,600)
MAX. HEIGHT m (ft)	3.29 (10.80)	2.90-3.15 (9.50-10.33)	3.12 (10.25)	3.28 (10.50)
BODY WIDTH m (ft)	2.44 (8.00)	2.44 (8.00)	2.44 (8.00)	2.44 (8.00)
CENTER-TO-CENTER OUTER TIRE WIDTH m (ft)	2.13 (7.00)	2.18 (7.16)	N/A	2.42 (7.95)
OVERALL LENGTH m (ft)	10.06 (33.00)	10.15 (33.31)	10.36 (34.00)	10.35, 10.45 (33.97),(34.28)
FRONT OVERHANG m (ft)	2.06 (6.75)	2.07 (6.78)	N/A	2.18 (6.90)
WHEELBASE m (ft)	4.95 (16.25)	4.95 (16.25)	4.70 (15.41)	5.32 (17.46)
REAR OVERHANG m (ft)	3.05 (10.00)	3.13 (10.28)	N/A	2.93 (9.62)
RADIUS TO INSIDE TIRE m (ft)	6.86 (22.50)	5.90 (19.37)	N/A	5.01 (16.45)
OUTSIDE TIRE CURB CLEARANCE RADIUS m (ft)	9.02 (29.58)	9.97 (32.70)	8.17 (26.80)	9.00 (29.52)
OUTSIDE BODY SWEEP RADIUS m (ft)	9.93 (32.58)	11.28 (37.00)	9.24 (30.33)	10.50 (34.45)
ENGINE (SMALLEST AVAILABLE ON THIS SIZE VEHICLE)	190 HP	6BTA5.9 190 HP	5.9L DIESEL (CUMMINS)	185 HP
TURN ANGLE	45.0°	41.0°	50.0°	45.0°

N/A = Not Available

TABLE A3 83/84 Passenger Type D School Bus Data

	BUS MANUFACTURER			
CATEGORY	Mfgr. W	Mfgr. X	Mfgr. Y	Mfgr. Z
LOADED WT. kg (lbs)	13,881 (30,580)	12,444 (27,414)	13,608 (29,978)	15,785 (34,775)
MAX. HEIGHT m (ft)	3.29 (10.80)	2.90-3.15 (9.50-10.33)	3.12 (10.25)	3.28 (10.50)
BODY WIDTH m (ft)	2.44 (8.00)	2.44 (8.00)	2.44 (8.00)	2.44 (8.00)
CENTER-TO-CENTER OUTER TIRE WIDTH m (ft)	2.13 (7.00)	2.18 (7.16)	N/A	2.42 (7.95)
OVERALL LENGTH m (ft)	12.12 (39.75)	12.11 (39.73)	12.12 (39.75)	12.07,12.16 (39.59),(39.91)
FRONT OVERHANG m (ft)	2.06 (6.75)	2.07 (6.78)	N/A	2.18 (6.90)
WHEELBASE m (ft)	7.01 (23.00)	6.02 (19.75)	5.79 (19.00)	7.03 (23.08)
REAR OVERHANG m (ft)	3.05 (10.00)	4.02 (13.20)	N/A	2.93 (9.62)
RADIUS TO INSIDE TIRE m (ft)	9.75 (32.00)	5.90 (19.37)	N/A	6.73 (22.07)
OUTSIDE TIRE CURB CLEARANCE RADIUS m (ft)	11.89 (39.00)	11.73 (38.50)	10.06 (33.00)	11.40 (37.41)
OUTSIDE BODY SWEEP RADIUS m (ft)	13.11 (43.00)	12.98 (42.60)	11.12 (36.50)	12.92 (42.40)
ENGINE (SMALLEST AVAILABLE ON THIS SIZE VEHICLE)	190 HP	6BT5.9 6BTA5.9 =190HP	5.9L DIESEL (CUMMINS)	185HP
TURN ANGLE	45.0°	41.0°	50.0°	45.0°

N/A = Not Available